Changes in Stratigraphic Nomenclature in the Cretaceous System East-Central Puerto Rico

By REGINALD P. BRIGGS

CONTRIBUTIONS TO STRATIGRAPHY

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By REGINALD P. BRIGGS

ABSTRACT

The system of informal stratigraphic nomenclature used previously for part of the Cretaceous section in east-central Puerto Rico is replaced by a formal nomenclature based on increased data gained from continued geologic mapping. Only the lower part of the Lower Cretaceous Series is not treated. The resulting changes in stratigraphic nomenclature are the following:

1. The Lower Cretaceous Torrecilla Breccia is formally established, replacing the informal formation D, formation K, and pre-Robles rocks in the Cayey, Comerío, and Barranquitas quadrangles, respectively. The Aguas Buenas Limestone Member is assigned to the base, and the Barros Tuff Member to the top, of the Torrecilla Breccia.
2. The Lower Cretaceous Barrancas Limestone Member of the Lower and Upper Cretaceous Magueyes Formation, Río Orocovis Group, is established as the formal name of the limestone unit of formation L in the Barranquitas quadrangle. Strata previously included in formation L and the Cariblanco Formation in the northern Barranquitas quadrangle are reassigned, chiefly to formations of the Río Orocovis Group; however, formation L strata underlying the Barrancas Limestone probably are stratigraphically equivalent to the Torrecilla Breccia.
3. The Río Bauta Member is established and assigned to the base of the Upper Cretaceous Pozas Formation; and the Botijas Limestone and Revés Members, previously included within the Coamo Formation, are reassigned to the Pozas.
4. The Toyosa Member is established and assigned to the top of the Upper Cretaceous Maravillas Formation.

INTRODUCTION

Detailed geologic mapping of Puerto Rico by the U.S. Geological Survey in cooperation with the Puerto Rico Economic Development Administration began in 1955 and continues at the time of this writing. Early efforts in this program were largely in east-central Puerto Rico, where the Cretaceous volcanic stratigraphy is extremely complex.

Early in the mapping program, it became clear that it would be difficult or impossible to solve many stratigraphic problems within the limits of individual mapping units, 7½-minute quadrangles. Informal stratigraphic nomenclature was therefore used where appreciable doubt existed as to identity, extent, or correlation of units and where it could be reasonably assumed that this doubt might be dispelled by later mapping in adjacent areas. In addition, formal stratigraphic names were applied in some areas where such use has since been found erroneous.

In this report, formal nomenclature is introduced where now considered feasible; some previous miscorrelations are corrected; and new correlations are made where necessary to clarify the stratigraphic relations of newly introduced or redescribed units. The report falls into four discrete parts, introducing or redefining the following: (1) The Lower Cretaceous Torrecilla Breccia and its Aguas Buenas Limestone and Barros Tuff Members, (2) the Lower Cretaceous Barrancas Limestone Member of the Lower and Upper Cretaceous Magueyes Formation, Río Orocovis Group, (3) the Río Bauta, Botijas, and Revés Members of the Upper Cretaceous Pozas Formation, and (4) the Toyosa Member of the Upper Cretaceous Maravillas Formation (fig. 1). No discussion of the overall Cretaceous stratigraphy of east-central Puerto Rico is attempted; only the previously mentioned units, all of which are stratigraphically above the informal formations A, B, C, and J (fig. 2), are dealt with here.

Some early correlations already have been changed (Glover and Mattson, 1967; Glover; 1967, 1969), and other modifications of stratigraphic nomenclature have been made (Nelson, 1966; Briggs, 1967). Faunal lists are not included; these either have been presented elsewhere (for example, Berryhill and others, 1960; Douglass, 1961; Kauffman, 1964; Glover, 1969) or will be included in future reports.

Reference to publications on the following quadrangles will aid the reader in understanding the discussion: Barranquitas (Briggs and Gelabert, 1962), Cayey (Berryhill and Glover, 1960), Ciales (Berryhill, 1965), Coamo (Glover, 1961), Comerío (Pease and Briggs, 1960), Corozal (Nelson, 1966, 1967), and Florida (Nelson and Monroe, 1966). In addition, the hydrogeologic map of Puerto Rico (Briggs and Akers, 1965) provides a general view of the region.

TERMINOLOGY

Terminology of volcanic rocks is various and inconsistent (Fisher, 1966), and no single proposed system of terminology seems to cover satisfactorily all varieties of volcanic rock. The volcaniclastic rock classification used in this report is shown in

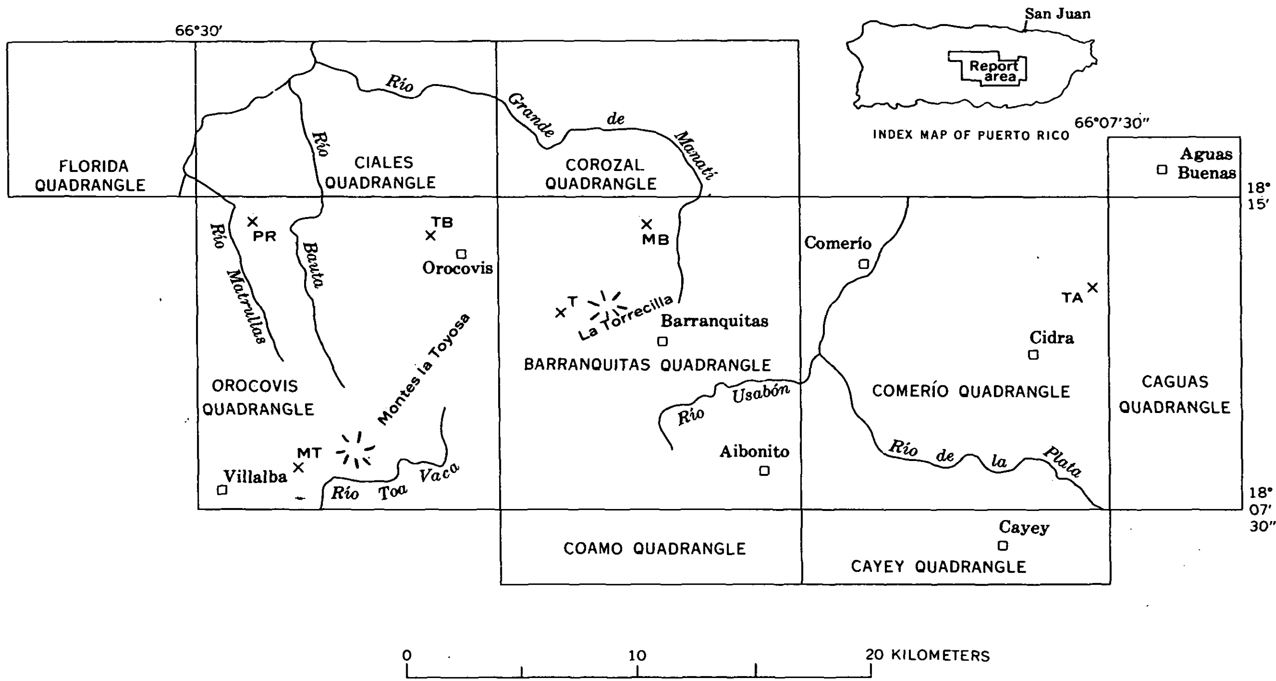

FIGURE 1.—Orocovis, Barranquitas, and Comerío quadrangles and adjacent areas, east-central Puerto Rico, showing type localities (X) for the following units: T, Torrecilla Breccia; TA, Aguas Buenas Limestone, and TB, Barros Tuff Members of Torrecilla Breccia; MB, Barrancas Limestone Member of Magueyes Formation; PR, Río Bauta Member of Pozas Formation; MT, Toyosa Member of Maravillas Formation.

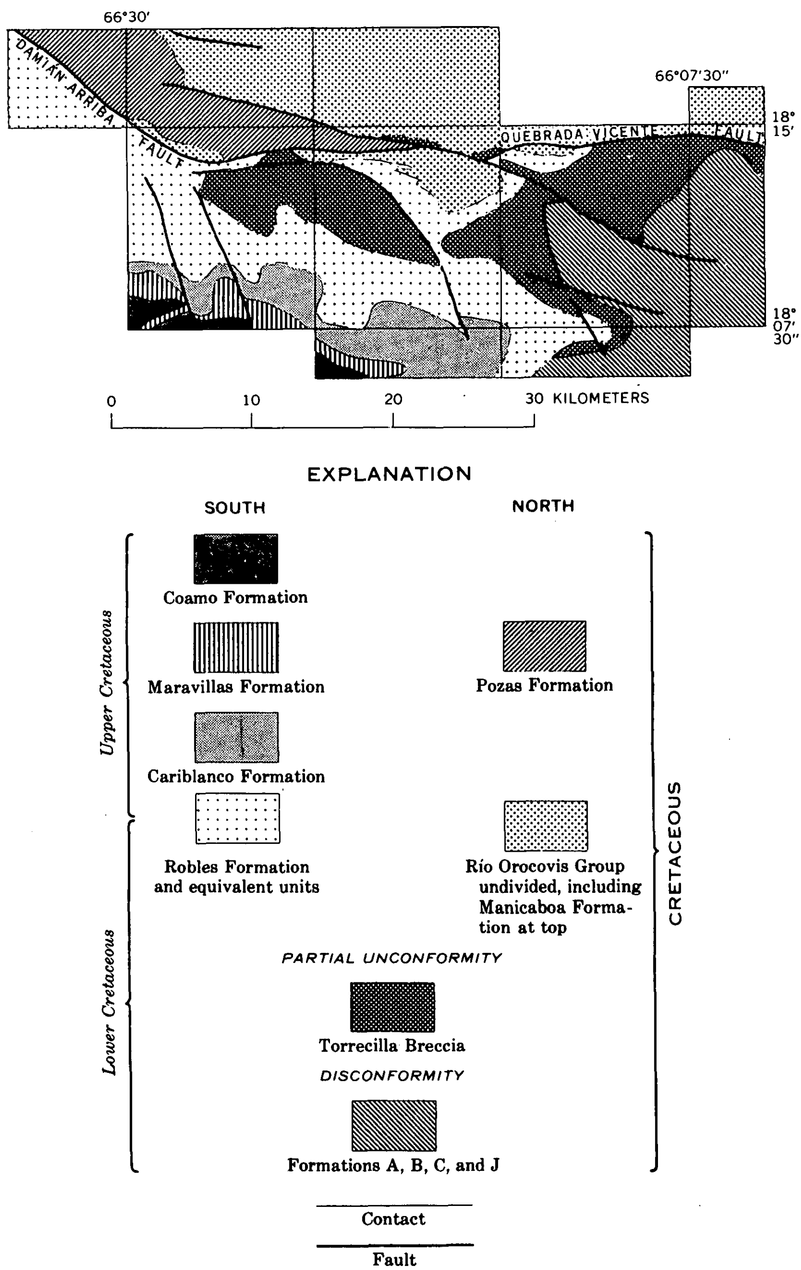

FIGURE 2.—Generalized geologic map of report area.

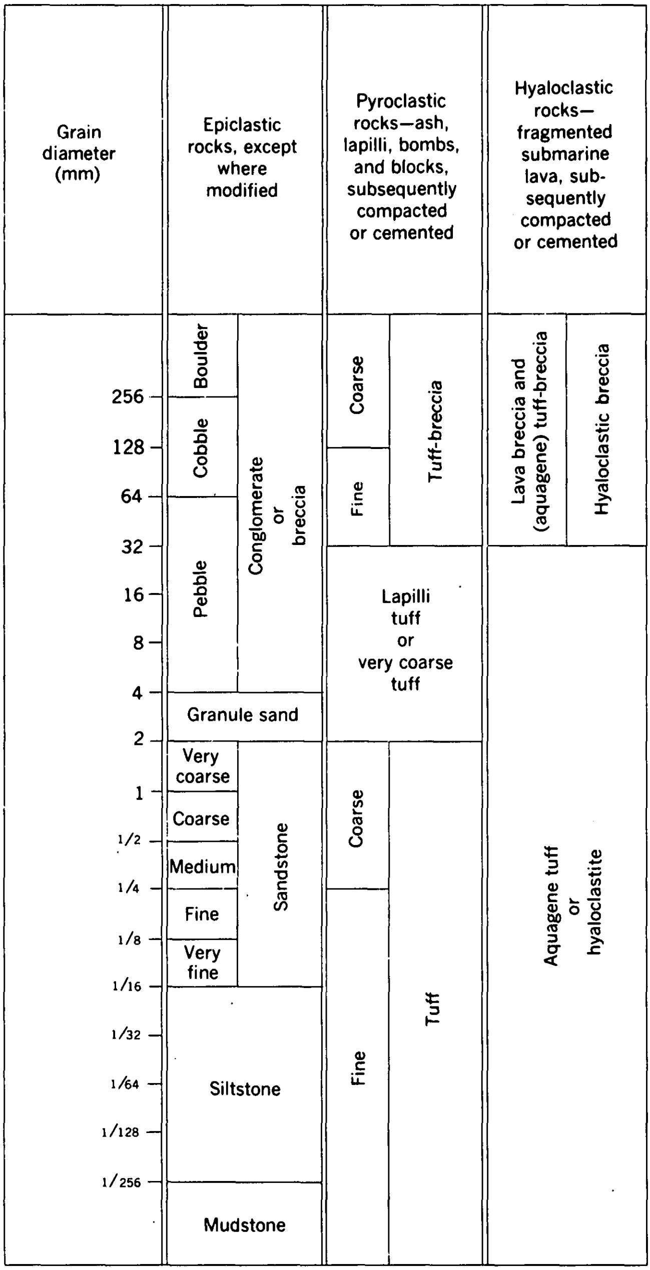

FIGURE 3.—Volcaniclastic rock classification used in this report. Chiefly modified from Fisher (1960, 1961), Rittman (1962), and Carlisle (1963).

figure 3. This classification is just broad enough in scope to cover the needs of this report; no attempt is made to classify all volcaniclastic rocks.

Most rocks in the units under discussion were deposited in a marine environment. Exceptions are chiefly in the Pozas Formation, where some rocks are known to have been, and others may have been, deposited subaerially.

Tuff and tuff-breccia may have remained at their initial site of deposition, having been deposited directly from a fall through air or water, or may have flowed appreciable distances downslope following the initial deposition. The character of layering suggests that postdepositional flowage usually occurred. These rocks include some ignimbrites.

Lava or lava flow as used here consist of rocks recrystallized from an extruded molten mass. Lava breccia consists of blocks of lava in a matrix of similar material. Lava and lava breccia are found in both marine and subaerial sequences. Pillow lavas can be considered special lava breccias or hyaloclastic breccias.

Well-known terms, such as andesite and crystal-lithic tuff, are not defined here. However, clarifications of two adjectives applied to common rock terms in the following pages are necessary:

Volcanic—a general adjective describing rocks believed to be composed chiefly of fragments of volcanic origin, no matter what the specific means of fragmentation and no matter whether in primary or reworked deposits; especially useful where uncertainty is high, as in areas of tropical weathering. Examples: both lava breccia and tuff-breccia are volcanic breccias; both tuffaceous sandstone and sandstone reworked from a volcanic provenance may be termed volcanic sandstones.

Tuffaceous—an adjective describing fragmental rocks chiefly composed of primary volcanic ejecta; modifies common rock terms for moderately well sorted to well-sorted, well-stratified water-laid deposits.

Layering thicknesses, in centimeters, are classified as suggested by Ingram (1954):

>100	Very thick.
30 to 100	Thick.
10 to 30	Medium.
3 to 10	Thin.
1 to 3	Very thin.
0.3 to 1	Thickly laminated.
<0.3	Thinly laminated.

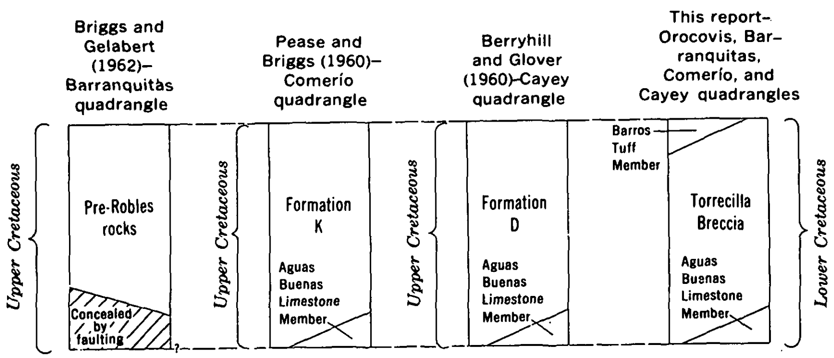

FIGURE 4.—Correlation of Torrecilla Breccia and its members with previous informal stratigraphic units.

THE LOWER CRETACEOUS TORRECILLA BRECCIA

Rocks of Early Cretaceous age previously referred to as formation D in the Cayey quadrangle (Berryhill and Glover, 1960), as formation K in the Comerío quadrangle (Pease and Briggs, 1960), and as pre-Robles rocks in the Barranquitas quadrangle (Briggs and Gelabert, 1962) are here named the Torrecilla Breccia for the double-peaked mountain, La Torrecilla, about 3 kilometers west-northwest of the town of Barranquitas in east-central Puerto Rico (figs. 1, 4).

The Aguas Buenas Limestone Member in the base of the Torrecilla Breccia was first described by Semmes (1919, p. 64–65). This limestone unit was correlated with basal strata of the Fajardo Formation by Berryhill and others (1960, p. 143) and was included in the basal parts of formation D (Berryhill and Glover, 1960) and formation K (Pease and Briggs, 1960). It is here formally reassigned.

The Barros Tuff Member, described below, is at the top of the Torrecilla Breccia in its western outcrop area.

FORMATION D, FORMATION K, AND PRE-ROBLES ROCKS

In the Cayey quadrangle, Berryhill and Glover (1960) described formation D as consisting of the fossiliferous Aguas Buenas Limestone Member, sporadically exposed at the base, and the overlying interlayered volcanic breccia, andesite lava flows, and tuffaceous sandstone. The breccia and sandstone are calcareous, and rocks of the unit as a whole commonly have a dusky-red cast.[1] The maximum thickness of formation D was given as about 200 m,

[1] Colors are in agreement with the "Rock-Color Chart" of the National Research Council (Goddard, 1948).

and the formation pinches out between the overlying Robles Formation and formation C about 5 km southwest of the town of Cayey (figs. 1, 2). No type locality was designated for formation D, but a section was described by Berryhill and Glover (1960).

Formation D of the Cayey quadrangle is contiguous with formation K of the Comerío quadrangle (Pease and Briggs, 1960). Formation K chiefly consists of crudely stratified coarsely clastic rocks ranging from volcanic breccia to coarse tuff. The Aguas Buenas Limestone Member crops out sporadically at the base of formation K, and discontinuous lenses of fossiliferous limestone and limestone-breccia about 10 meters thick are found in other parts of the section. Well-stratified units of calcareous thin-bedded tuffaceous sandstone and siltstone as much as 50 m thick occur intermittently throughout formation K; lava flows are present, most commonly in the upper few hundred meters where locally they predominate. Rocks in the upper part commonly have a dusky-red cast, similar to those in formation D. The maximum thickness of formation K of the Comerío quadrangle is 2,050 m, considerably thicker than formation D of the Cayey quadrangle. Although no type section was designated in the Comerío quadrangle, Pease and Briggs (1960) gave brief descriptions of several localities in which rocks typical of formation K are well exposed. In the northernmost part of the quadrangle, north of the Quebrada Vicente fault, rocks that were included in formation K by Pease and Briggs (1960) now are included within the Río Orocovis Group (Nelson, 1966).

In the eastern part of the Barranquitas quadrangle (fig. 1), the pre-Robles rocks of Briggs and Gelabert (1962) are contiguous with the upper part of formation K. Lava and lava breccia are the most common rock types in the pre-Robles rocks, but very thick bedded tuff-breccia and volcanic conglomerate also are common, and thin- to thick-bedded units of tuff and tuffaceous sandstone and siltstone are present locally. A total of at least 1,200 m and perhaps as much as 1,800 m of pre-Robles rocks is exposed in the Barranquitas quadrangle, but the full thickness is not known because the bottom of the section is faulted out. However, it now seems reasonable to assume that all pre-Robles strata in the Barranquitas quadrangle are stratigraphically equivalent to rocks included in formation K in the Comerío quadrangle. The Aguas Buenas Limestone Member is not present in the Barranquitas quadrangle, and the exposed pre-Robles section is at least 200 m and perhaps 800 m thinner than formation K.

Recent geologic mapping by the writer of this paper in the Orocovis quadrangle (fig. 1) has shown that an appreciable section of pre-Robles rocks also is present in this area. Detailed measurement of the thickness is precluded by structural complications, but it is probably at least 1,000 m thick, and no base is present. Very thick bedded coarse tuff-breccia is the most common lithologic type, but finer breccia and very thick bedded to thick-bedded coarse tuff also are found. Units that contain lava grading upward to lava breccia, tuff-breccia, and aquagene tuff are present near the top of the section, between 1 and 2 km south of the town of Orocovis. Thin-bedded tuffaceous sandstone and siltstone are uncommon in the pre-Robles rocks of the Orocovis quadrangle as compared with areas to the east. The Barros Tuff Member, described below, occurs at the top of the pre-Robles rocks in all but the easternmost Orocovis quadrangle exposures.

TYPE SECTION AND REFERENCE SECTIONS

The type section of the Torrecilla Breccia is here designated as the series of exposures of very thick bedded and thick-bedded tuff-breccia, lava breccia, and related rocks in the Barranquitas quadrangle along Highway 156 between 40,180 m N., 160,950 m E. and 41,140 m N., 160,990 m E. (Puerto Rico rectangular coordinate system), about 2.1 km west of the western peak of La Torrecilla; also included in the type section are the nearby exposures in the Río Botijas, about 100 m east of and parallel to this segment of Highway 156.

Other sections in which the Torrecilla Breccia is well exposed in the Barranquitas quadrangle are on Highway 770 along the western and northwestern flanks of La Torrecilla (largely tuff-breccia and tuff) and along the course of the Río Usabón from the base of the Robles Formation, 3 km airline east-southeast of the town of Barranquitas, eastward to the confluence of the Río Usabón and Río de la Plata (largely lava breccia and lava). In addition, tuff-breccia, lava breccia, and volcanic conglomerate of the upper part of the Torrecilla Breccia crop out magnificently in the vertical walls of the Cañón de San Cristóbal, about 3 km southeast of Barranquitas, but here the exposures are rather inaccessible.

In the Comerío quadrangle, tuff-breccia, lava breccia, lava, and tuff of the upper part of the Torrecilla Breccia are well exposed along Highway 775 from 1 km south of the town of Comerío southward about 3.9 km airline to the saddle at the head of Quebrada Piña, about 0.6 km west of Cerro Viento Caliente; along

Highway 173 from the saddle at the head of Quebrada Galindo, 0.7 km north of Cerro Plana, to a point 0.6 km northeast of the meander core at Proyecto La Plata; and along Highway 14 from the vicinity of Cayey west-northwestward about 5 km airline to the point where the highway exposures pass into the overlying Robles Formation.

Tuff-breccia, lava breccia, and tuff of the lower Torrecilla Breccia are best exposed on Highway 782 from the point where the highway crosses Quebrada Ceiba, about 4.0 km airline north of the town of Cidra (fig. 1), to the outcrop of the Aguas Buenas Limestone Member, 2.2 km airline north-northwest of Cidra.

Fresh rock in these sections commonly is dark gray, greenish gray, and bluish black, but dark-reddish tints are characteristic of strata in parts of the upper Torrecilla Breccia.

DISTRIBUTION, THICKNESS, AND DEPOSITIONAL ENVIRONMENT

The Torrecilla Breccia crops out widely in east-central Puerto Rico (fig. 2). It is composed chiefly of very thick bedded fragmental volcanic rocks. Tuff-breccia and lava breccia predominate, but coarse tuff is common; andesite lava is common in the upper part of the formation and is present locally in other parts of the formation. Limestone lenses and units of thin-bedded tuffaceous sandstone and siltstone are relatively minor but widespread components, especially in the eastern outcrop areas. Exclusive of lavas and lava breccias, most rocks are slightly to moderately calcareous.

The Aguas Buenas Limestone Member occurs sporadically in the base of the formation, and the Barros Tuff Member is present in the top in western outcrop areas. The thickest known section of the Torrecilla Breccia is 2,050 m in the Comerío quadrangle. In the western area of outcrop, a thickness of only about 1,000 m is estimated, but the base of the formation is not exposed; the Torrecilla may be appreciably thicker here. The Torrecilla thins to zero toward the southeast (fig. 2).

The bulk of the Torrecilla Breccia was laid down in a marine environment, as indicated by the presence of calcareous units containing marine fossils, well-stratified units, and crude pillowing in some lavas. However, the uppermost Torrecilla Breccia in eastern outcrops may well have been deposited in a largely subaerial environment, as is suggested by the reddish cast of the rocks and an absence of evidence for marine deposition at most places where this reddish cast is found.

AGUAS BUENAS LIMESTONE MEMBER

The Aguas Buenas Limestone Member is here assigned to the base of the Torrecilla Breccia. Although the "Aguas Buenas limestone" has been in the geological literature since first described by Semmes in 1919, no formal descriptions of type locality or type section have been made. In order to make use of this generally accepted stratigraphic name, the Aguas Buenas Limestone Member is here redefined.

The Aguas Buenas Limestone Member is named for the town of Aguas Buenas, eastern Puerto Rico (fig. 1). The type area is a zone of well-developed karst topography in Barrio Sumidero in the Caguas quadrangle about 3 km due south of Aguas Buenas. Although the Caguas quadrangle has not been mapped in detail, correlation of the limestone occurrence in Barrio Sumidero with the limestone that trends northeast from the town of Cidra in the Comerío quadrangle is considered definite (Semmes, 1919; Pease and Briggs, 1960). The type locality is here designated as the quarry (41,430 m N., 183,640 m E.) on the northwest side of Quebrada La Zapera, 4.1 km north-northeast of Cidra, in the Comerío quadrangle (fig. 1). Here, about 30 m of dark-gray thick-bedded to very thick bedded finely crystalline limestone which bears an extensive rudist and gastropod fauna is exposed. At the type locality the top of the member is faulted out, but nearby it is overlain by thin-bedded tuffaceous sandstone and siltstone that grade upward into coarser, very thick bedded and thick-bedded volcanic strata of the Torrecilla Breccia; the base of the member is poorly exposed, but apparently it rests on hydrothermally altered volcanic rock. Locally the Aguas Buenas Limestone Member contains intercalations of thin- and medium-bedded calcareous volcanic sandstone and siltstone, but in most outcrops it is virtually pure crystalline limestone.

Along strike northeast of Cidra (figs. 1, 2), the Aguas Buenas Limestone Member rests for the most part on intrusive rocks or altered strata. The member locally exhibits evidence of alteration in its lower part; apparently, in this area the Aguas Buenas Limestone Member and other rocks at the base of the Torrecilla Breccia were virtually impervious to magma and hydrothermal solutions, and only the underlying rocks were extensively affected (Pease and Briggs, 1960). Elsewhere, the Aguas Buenas Limestone Member rests disconformably on strata assigned to formations A and C in the Cayey quadrangle (Berryhill and Glover, 1960) and formation J in the Comerío quadrangle (Pease and Briggs, 1960).

The thickness of the Aguas Buenas Member generally ranges from 0 to 60 m; it is a lenticular reef limestone, which is present along only about three-fourths of the exposed base of the Torrecilla Breccia (Berryhill and Glover, 1960; Pease and Briggs, 1960).

Fossils collected from the Aguas Buenas Limestone Member indicate an Early Cretaceous age, probably Albian (Douglass, 1961; N. F. Sohl, oral and written commun., 1956–1967).

BARROS TUFF MEMBER

The Barros Tuff Member of the Torrecilla Breccia is here named for Barrio Barros, just northwest of the town of Orocovis in the Orocovis quadrangle (fig. 1). The type section is along an eroded foot trail that descends a ridge about 1 km northwest of the town, between 44,280 m N., 156,120 m E. and 44,380 m N., 155,850 m E. Here, the base and most of the member are exposed; the top is concealed. The coarse tuff that is the predominant component of this unit is moderately to deeply weathered in most outcrops, generally ranging from yellowish and grayish brown to reddish brown. In the type section the member consists of moderately weathered thick-bedded and very thick bedded coarse crystal-lithic tuff that locally grades into coarser tuff and fine breccia interlayered with units of thin-bedded tuffaceous sandstone and siltstone 1 to 2 m thick.

Crystal components are chiefly euhedral and fragmental pyroxene and feldspar, and lithic components are chiefly andesite lava. Locally, coherent blocks of tuffaceous sandstone and siltstone as much as 1 m across are found within the coarse tuff. Attitudes of thin-bedded strata in the type section are not consistent. Excellent outcrops on Highway 143, southwest of Barranquitas, show that similarly inconsistent attitudes in strata of the overlying Robles Formation are due to intraformational folds and slumps. Although proof of similar relations in the Barros Tuff Member is difficult owing to lack of exposures, the inconsistent attitudes and the blocks in the coarse tuff do suggest penecontemporaneous, probably marine, sliding or flowing. The inconsistent attitudes also made accurate measurement of thickness impossible, but a thickness of 80 to 100 m is estimated in the type section.

The thin-bedded tuffaceous sandstone and siltstone interbeds in the Barros Tuff Member are identical with beds in the overlying Robles Formation (Pease and Briggs, 1960), indicating that the upper contact is gradational. The basal contact appears conformable in the type section and elsewhere.

The character of the coarse tuff in the Barros Tuff Member differs somewhat from place to place. In some outcrops feldspar predominates over pyroxene, and the rock is more resistant to weathering than in the type locality, locally forming boulders; in others, the Barros can be classified as a crystal-vitric tuff composed chiefly of pyroxene and feldspar crystals and indeterminate aphanitic material interpreted as devitrified volcanic glass. In the latter outcrops, the Barros Tuff Member approaches olive gray and bears a strong resemblance to the Cotorra Tuff, a hyaloclastite or aquagene tuff that crops out in the Upper Cretaceous section of the same general area (Briggs, 1967). In many places, particularly in the southern part of the outcrop area, the thin-bedded units or blocks that are in the type section are uncommon or absent. In the southern part of the outcrop area, the Barros Tuff Member may be seen grading downward into coarsely fragmental rocks typical of the Torrecilla Breccia.

The member crops out only in the Orocovis quadrangle. It perhaps ranges from 0 to 120 m in thickness.

No fossils were recovered from the Barros Tuff Member, but the relations described below demonstrate that most likely it is Early Cretaceous (Albian) in age.

CONTACT RELATIONS OF THE TORRECILLA BRECCIA

Although there are no striking unconformities at the base of the Torrecilla Breccia, it is plain that the contact is not gradational. The Torrecilla apparently overlaps formation A and formation C in the Cayey quadrangle (Berryhill and Glover, 1960) and formation J in the Comerío quadrangle (Pease and Briggs, 1960). In the Comerío quadrangle, local angular unconformities were observed. In addition, the presence of the Aguas Buenas Limestone Member in the base of the Torrecilla suggests at least an hiatus in volcanism. The ages of formations A, C, and J are not known; they are broadly similar in character to the Torrecilla Breccia, however, so there is no reason to believe there was a great lapse of geologic time between their deposition and the deposition of the Torrecilla. The Torrecilla Breccia, then, rests unconformably on rocks that may not be appreciably older than the Torrecilla.

West of Barranquitas (fig. 1), the Torrecilla Breccia and the Barros Tuff Member grade upward into the Robles Formation. East of Barranquitas, however, the contact appears to be disconformable. On the north side of the Río Usabón in the eastern part of the Barranquitas quadrangle, the Robles Formation is considerably thinner than it is in adjacent areas (Briggs and

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Gelabert, 1962). This thinning may be ascribed partly to interfingering of the upper Robles with volcanic rocks, chiefly lava, referred to formation L by Briggs and Gelabert (1962), but here reassigned to the Río Orocovis Group. However, in this vicinity much of the Torrecilla Breccia has a reddish hue, and there is volcanic conglomerate at the top. These relations suggest that the Robles may have been deposited first around, then over, a hill in an eroded Torrecilla terrane.

The reddish colors and absence of evidence of marine deposition of the upper Torrecilla over much of the eastern outcrop area suggest that subaerial accumulation of upper Torrecilla rocks may have been widespread. Moreover, the reeflike Río Matón Limestone Member (Berryhill and Glover, 1960) is present in the base of the Robles Formation only east of Barranquitas, suggesting shallow seas and perhaps a reef fringing a volcanic landmass. In addition, about 2 km south-southeast of Barranquitas a lens of jasperoid at the Robles-Torrecilla contact perhaps represents an ancient soil accumulation. Thus, the upper contact of the Torrecilla Breccia is conformable on the west and largely disconformable on the east. This suggests that the Torrecilla Breccia may be thicker in the west where no base is exposed than it is in the east.

AGE AND REGIONAL RELATIONS

The age of the Torrecilla Breccia is Early Cretaceous, probably entirely Albian; the Aguas Buenas Limestone Member in the base probably is Albian, and the overlying Robles Formation is now known to range from Early Cretaceous, Albian, to Late Cretaceous, Santonian, in age (Briggs, 1967). The previous assignment of rocks now labeled Torrecilla Breccia to the Upper Cretaceous System (Berryhill and others, 1960; Pease and Briggs, 1960; Briggs and Gelabert, 1962) was incorrect (fig. 4).

The sparsely detailed geologic mapping and widespread intrusive activity and related metamorphism in areas east of the Comerío quadrangle make detailed correlations eastward difficult. In the Juncos quadrangle (Broedel, 1961), immediately east of the Caguas quadrangle (fig. 1), a mineralized marble unit that strikes east to southeast and dips steeply northward crops out within a metamorphosed terrane. Structural and spatial relations suggest that this unit is an extension of the Aguas Buenas Limestone Member. If this is true, the metamorphosed very thick bedded volcanic rocks that crop out for a few kilometers northward from the marble to the line of an extensive fault zone are laterally equivalent to the Torrecilla Breccia.

Strata exposed in northeastern Puerto Rico, north of this fault zone, include the Fajardo Formation, stated by Berryhill, Briggs, and Glover (1960) to be stratigraphically equivalent to the rocks herein named the Torrecilla Breccia. A general correlation of the Torrecilla Breccia with the lower part of the Fajardo Formation doubtless is valid, because both the Torrecilla and the lower Fajardo now are considered Early Cretaceous, probably Albian, in age. The upper Fajardo Formation, however, probably is equivalent to the lower Robles Formation. Although the report of Berryhill, Briggs, and Glover (1960) may be interpreted as including the Aguas Buenas Limestone Member in the base of the Fajardo Formation, such an assignment is rejected here. The Fajardo Formation crops out only in northeastern Puerto Rico, whereas the Aguas Buenas Limestone Member crops out only in east-central Puerto Rico; nowhere are they in contact.

In the western part of the Orocovis quadrangle, the Torrecilla Breccia and its Barros Tuff Member are concealed by younger strata. The overlying Robles Formation and equivalent strata, however, are more or less continuously exposed westward to the vicinity of the Utuado batholith in the Jayuya quadrangle (Mattson, 1968). Here again the base of the Robles Formation is exposed, resting on several hundred meters of moderately to highly metamorphosed tuff similar in many respects to the Barros Tuff Member. Mattson (1967) has named this occurrence the Jayuya Tuff. A general stratigraphic equivalence of the Jayuya Tuff and the Torrecilla Breccia appears fairly certain, although the lack of outcrop continuity in this complex area and the complete lack of fossil evidence preclude usage of one stratigraphic name throughout.

THE LOWER CRETACEOUS BARRANCAS LIMESTONE MEMBER OF THE MAGUEYES FORMATION, RIO OROCOVIS GROUP

The Barrancas Limestone Member of the Magueyes Formation is here named for Barrio Barrancas, Municipio of Barranquitas, Puerto Rico, where the unit is well exposed in quarries (fig. 1). On the geologic map of the Barranquitas quadrangle (Briggs and Gelabert, 1962), this unit is described as the limestone unit of formation L (fig. 5). The type locality is a quarry centering at 44,170 m N., 164,110 m E., where almost 60 m of very thick bedded and thick-bedded medium-dark-gray to grayish-black highly fossilferous finely crystalline limestone crops out. Several meters of fossiliferous mudstone occur near the base. Doubtless this mudstone was very calcareous when fresh, but the outcrop has been

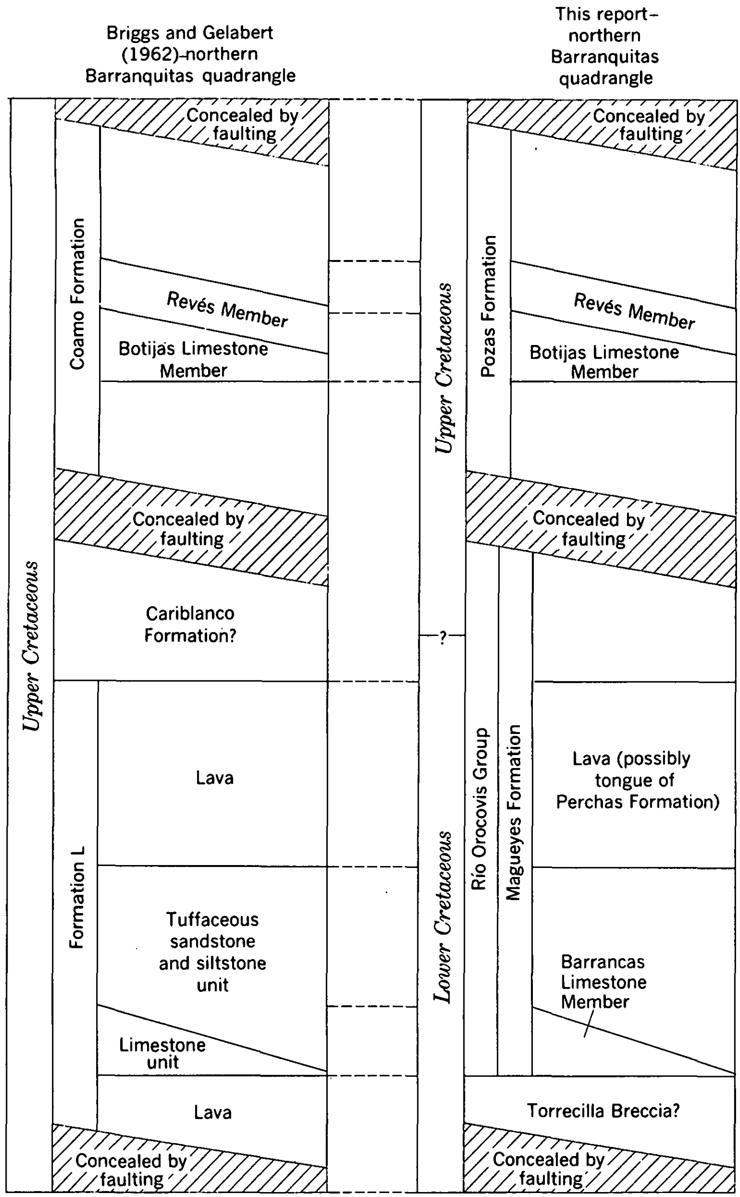

FIGURE 5.—Changes in nomenclature pertaining to the Magueyes and Pozas Formations.

leached. Fossils in the member are chiefly rudists and gastropods, indicating that the rocks are organic-reef or near-reef deposits.

The upper contact of the Barrancas Member is not well exposed at the type locality, but elsewhere it is seen to be gradational over about 1 m into rocks labeled on the geologic map of the Barranquitas quadrangle as the tuffaceous sandstone and siltstone unit of formation L (Briggs and Gelabert, 1962). Nowhere is the lower contact of the Barrancas Limestone Member well exposed. In most outcrops the Barrancas dips into the lower part of the face of an escarpment and away from a large fault zone that contains strata which form a topographic lowland; talus or colluvium from the Barrancas and overlying rocks commonly conceal the base of the Barrancas. Available outcrops indicate, however, that the Barrancas Limestone Member rests with structural conformity on volcanic rocks, chiefly lavas, that were assigned to formation L by Briggs and Gelabert (1962).

The Barrancas Limestone Member is exposed nearly continuously for 2.2 km west and 0.9 km east of the type locality. Farther west it occurs sporadically at the same horizon for about 2.0 km and then is faulted out; to the east it also crops out sporadically at the same horizon for an airline distance of about 4 km through a complexly faulted terrane. The thickest section in outcrop outside the type area is in the valley of the Río Hondo, the easternmost occurrence of the member. Nowhere does the Barrancas Limestone Member greatly exceed 60 m in thickness.

A limestone occurrence south of the Río Hondo that was included in the limestone unit of formation L by Briggs and Gelabert (1962) here is excluded from the Barrancas Limestone Member for reasons given later in this paper.

AGE

The fauna of the Barrancas Limestone Member indicates that the unit is Early Cretaceous, Albian, in age (N. F. Sohl, written commun., 1963). Moreover, there is a strong resemblance between the fauna of the Barrancas Member and the fauna in the Río Matón Limestone Member (Berryhill and Glover, 1960) at the base of the Robles Formation (Pease and Briggs, 1960) in the vicinity of Comerío (fig. 1), about 8 km east of the type area of the Barrancas Member. The Río Matón Limestone Member, formerly considered to be of Early and Late Cretaceous age, is now recognized as Early Cretaceous, Albian, in age (N. F. Sohl, oral commun., 1967).

REGIONAL RELATIONS AND ASSIGNMENT OF THE BARRANCAS LIMESTONE MEMBER TO THE MAGUEYES FORMATION

At the time the geology of the Comerío and Barranquitas quadrangles was mapped (1955–58), little was known of the geology of areas to the north and west. To produce a geologic map that was both consistent with the known geology and internally consistent, Pease and Briggs (1960) introduced the informal formation L in the Comerío quadrangle, and in the Barranquitas quadrangle Briggs and Gelabert (1962) carried formation L westward. They also tentatively correlated tuffaceous sandstone, tuff-breccia, and volcanic conglomerate along the northern border of the Barranquitas quadrangle with the Cariblanco Formation that is well exposed at the south edge of the quadrangle and in the Coamo quadrangle (Glover, 1961) to the south (figs. 1, 2).

Later work by Berryhill (1965) in the Ciales quadrangle to the northwest and by Nelson (1966, 1967) in the Corozal quadrangle (fig. 1) to the north has shown that modification of this early stratigraphy is necessary.

The Río Orocovis Formation was defined by Berryhill (1965, p. 19–45) in the Ciales quadrangle. As originally described, the formation included the Magueyes, Perchas, and Avispa Members and an interfingering basalt tuff member. Nelson (1966, p. 6–11) raised the Río Orocovis to group rank (fig. 5) and the members to formations. He named the basalt tuff unit the Los Negros Formation. The Río Orocovis Group is believed to be stratigraphically equivalent to the Robles Formation of Early to Late Cretaceous (Albian to Santonian) age (Briggs, 1967), chiefly on the basis of lithologic comparison.

Strata along the north edge of the Barranquitas quadrangle that tentatively were correlated with the Cariblanco Formation are now clearly part of the Magueyes Formation (Nelson, 1966, p. 8–9). Moreover, intercalations of basalt lava are common within the tuffaceous sandstone and siltstone of the Magueyes Formation in the Corozal quadrangle (Nelson, 1967); thus, the thick basalt lava unit below the supposed Cariblanco Formation and above the tuffaceous sandstone and siltstone unit of formation L on the Barranquitas geologic map (Briggs and Gelabert, 1962) is here included in the Río Orocovis Group (fig. 5). It is either part of the Magueyes Formation or possibly a tongue of the Perchas Formation. The tuffaceous sandstone and siltstone unit of formation L, below this lava tongue, falls logically within the Magueyes Formation and rests on the Barrancas Limestone Member. The Barrancas Limestone Member here is assigned to the Magueyes Formation and is tentatively identified as the basal unit of the formation. If this assignment is correct, the base of the Magueyes is exposed only in the Barranquitas quadrangle (fig. 5); if the Barrancas Member is not considered the base, no exposures of the base of the Magueyes Formation are known.

Strata beneath the Barrancas Limestone Member also were assigned to formation L by Briggs and Gelabert (1962). Tentatively, these rocks now are considered correlative with the upper part of the Torrecilla Breccia (fig. 5).

Other rocks formerly included in formation L also are reassigned, and formation L is abandoned. Basalt lava and related rocks north of the Quebrada Vicente fault in the northeastern part of the Barranquitas quadrangle and northwestern part of the Comerío quadrangle are part of the Perchas Formation; the correlation of similar rocks south of the Quebrada Vicente fault and north of a west-northwest-trending fault through the northeastern Barranquitas quadrangle (Briggs and Gelabert, 1962) is less certain, but the rocks are certainly of the Río Orocovis Group and probably of the Perchas Formation. Former formation L strata south of the Damián Arriba–Quebrada Vicente fault continuum now are included in the Río Orocovis Group, probably in the Perchas Formation and perhaps equivalent in the upper part to the Avispa Formation (fig. 2).

The limestone lens south of the Río Hondo that was formerly assigned to the "limestone unit of Formation L" (Briggs and Gelabert, 1962) is excluded from the Barrancas Limestone Member for several reasons. The Barrancas Limestone Member of the Magueyes Formation here is correlated with the Río Matón Limestone Member at the base of the Robles Formation. The limestone lens south of the Río Hondo therefore no longer can be correlated with the Barrancas Member, for it overlies a part of the Robles as well as strata now considered a part of the Río Orocovis Group. The original correlation was made by lithologic comparison; no fossil evidence is available on the age of this limestone lens.

THE RIO BAUTA, BOTIJAS LIMESTONE, AND REVES MEMBERS OF THE UPPER CRETACEOUS POZAS FORMATION

The Pozas Formation first was described by Berryhill (1965, p. 49–61), in the Ciales quadrangle (fig. 1). There and in the Florida quadrangle (Nelson and Monroe, 1966) to the west, the Pozas consists of more than 2,000 m of tuff, volcanic breccia, conglomerate, lava, limestone, and related rocks, resting on the volcaniclastic Manicaboa Formation (figs. 2, 6). Faulting obscures the upper contact.

The Minguillo Lava Member, which is 300 m thick, is the basal unit of the Pozas in northern exposures in the Ciales and Florida quadrangles. It is overlain by the Blacho Tuff Member, a unit about 500 m thick that contains resistant ash-flow lenses. In

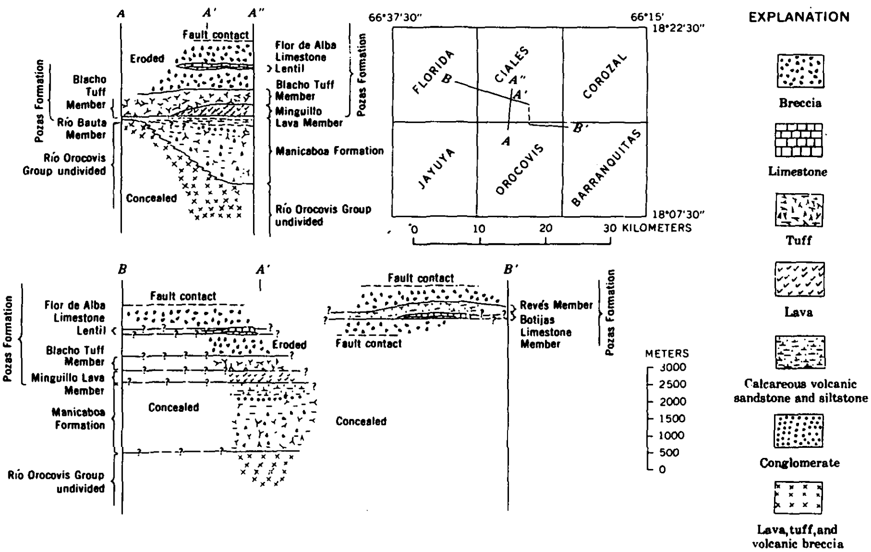

FIGURE 6.—Facies changes in the Pozas Formation. Map shows approximate location of sections.

outcrops in the southern parts of these quadrangles, the Minguillo Member is absent and the Blacho Tuff Member is at the base of the Pozas (fig. 6, section *A–A"*).

The bulk of the Pozas overlying the Blacho Member is referred to informally by Berryhill as the upper breccia member. The top of this member is not exposed. Within the upper breccia member, about 600 m above the top of the Blacho Member, is the Flor de Alba Limestone Lentil (Nelson and Monroe, 1966, p. C10–C12), a lenticular limestone reef that is locally more than 200 m thick (fig. 6, section *B–B'*). Other thinner and less extensive limestone lenses also are found within the upper breccia member.

Strata now assigned to the Pozas Formation in the Ciales quadrangle formerly were assigned to the Coamo Formation of southern Puerto Rico (Berryhill, 1961; 1965, p. 49). Similar rocks exposed in a narrow graben in the northwestern part of the Barranquitas quadrangle (Briggs and Gelabert, 1962) were also assigned to the Coamo. Recent geologic mapping by the writer of this paper in the intervening Orocovis quadrangle has demonstrated that the Pozas of the Ciales quadrangle is continuous with the so-called Coamo of the Barranquitas quadrangle. The strata in the northwestern Barranquitas quadrangle formerly assigned to the Coamo Formation therefore are reassigned to the Pozas Formation (figs. 2, 5).

RIO BAUTA MEMBER

Calcareous mudstone, siltstone, and sandstone, conglomerate, and limestone that crop out in a narrow discontinuous west-trending band from the north-central to northwestern section of the Orocovis quadrangle are here named the Río Bauta Member of the Pozas Formation for exposures in the valley of the Río Bauta, a tributary of the Río Grande de Manatí (fig. 1). The type section is along an unpaved road that runs west-northwest downhill into the Río Matrullas drainage from the saddle that forms the lowest point on the divide between the Río Matrullas and the drainage basin of the Río Bauta. The base of this section is at 45,420 m N., 147,460 m E. and the top is at 45,200 m N., 147,970 m E. The member also is well exposed along Highway 157 between 45,050 m N., 148,660 m E. and 44,870 m N., 149,540 m E., and limestone lenses within the member crop out on Highway 157 in the vicinities of 44,820 m N., 150,730 m E. and 45,170 m N., 152,850 m E.

The outcrop of the Río Bauta Member is restricted to a structurally complex zone on the north side of the Damían Arriba fault (Berryhill, 1965; Nelson and Monroe, 1966). There it forms the base of the Pozas Formation and is overlain by the Blacho Tuff Member (fig. 6, section *A–A″*). The Río Bauta Member rests with sharp unconformity on volcanic rocks, largely lava, of the Río Orocovis Group. Elsewhere, the Río Orocovis has been extensively subdivided (Berryhill, 1965; Nelson, 1967). In the type area of the Río Bauta Member, however, almost all rock types characteristic of the Río Orocovis Group are exposed within an extensively faulted and rather small and isolated area; thus, no reliable correlation with subordinate units within the Río Orocovis is possible, and that group has not been subdivided here.

The contact of the Río Bauta Member with the overlying Blacho Tuff Member is gradational. In the upper few meters of the Río Bauta Member, medium to thick beds of noncalcareous dullgrayish-red to dusky-red-purple mudstone and tuff characteristic of the Blacho Member are interlayered with calcareous beds more typical of the Río Bauta Member. The contact is drawn at the top of the highest calcareous bed.

The Río Bauta Member is about 100 m thick. In the type section, the base is composed of about 10 m of grayish- to dusky-red conglomerate, in which clasts of basalt and andesite lava typical of the Río Orocovis Group are as much as 40 cm long. Most clasts are subround, but a few are segments of polygonal columns of andesite lava. The matrix of the conglomerate is clayey volcanic sandstone. This basal part of the Río Bauta Member is well exposed only in the type section.

The bulk of the member is composed of dark-gray, bluish-gray, and grayish-brown thin- and medium-bedded calcareous volcanic sandstone, siltstone, and mudstone; locally it contains an abundant gastropod fauna in addition to other fossils. East of the type section, discontinuous dark-gray limestone lenses are found; in the easternmost outcrops, one faulted lens of limestone may be more than 10 m thick.

The Río Bauta Member is included in the Pozas Formation because of its gradational relationship with the overlying Blacho Tuff Member and because calcareous units, for example the Flor de Alba Limestone Lentil, are a characteristic of the Pozas despite its predominantly noncalcareous nature.

CORRELATION OF THE RIO BAUTA MEMBER WITH STRATA TO THE NORTH

In the type area of the Río Bauta Member, the basal Pozas dips northward beneath younger strata on the south flank of a minor syncline. About 4 km north, in the Ciales quadrangle, the north flank of the syncline again exposes the base of the Pozas Formation (fig. 2), but there Berryhill (1965) placed the base of the Pozas Formation at the bottom of the Blacho Tuff Member. The Río Bauta Member was not mapped, and the Pozas is shown resting on the Manicaboa Formation, which is more than 2,000 m thick and rests in turn on the Río Orocovis Group (fig. 6). According to Berryhill (1965, p. 46, 49), the Pozas-Manicaboa contact is conformable except in the vicinity of Capilla del Carmen in the Ciales quadrangle, where he reported an angular discordance. Artificial exposures made since Berryhill mapped the area indicate that the apparent discordance there resulted from relatively minor, previously undiscovered faulting; the Pozas-Manicaboa contact is conformable throughout.

Berryhill concluded that the upper Manicaboa was deposited in shallow water, whereas the lower Manicaboa was laid down in deeper seas. He further noted that pebbles, cobbles, and water-worn boulders were widespread in the upper Manicaboa (Berryhill, 1965, p. 48). The uppermost strata in the Manicaboa in the vicinity of Capilla del Carmen are calcareous sandstone and siltstone similar to the predominant rock types in the Río Bauta Member, but no conglomerate was seen in the upper 300 m of the Manicaboa Formation in this area.

The Río Bauta Member of the Pozas Formation plainly is equivalent stratigraphically to a presently unknown part of the upper Manicaboa Formation, though no fossils have been recovered from the upper Manicaboa. Both units are overlain conformably by the Blacho Tuff Member of the Pozas Formation (except toward the north where the Minguillo Lava Member of the Pozas intervenes), and the Río Bauta Member and the uppermost Manicaboa Formation are similar lithologically.

On the other hand, the Río Bauta Member cannot be correlated with the entire Manicaboa Formation, for coarse tuff and volcanic breccia are among the principal constituents of the Manicaboa (Berryhill, 1965, p. 46), and these rock types are not present in the Río Bauta Member. Moreover, rocks similar to those in the lower Manicaboa occur within the Río Orocovis Group (Berryhill, 1965, p. 45; Nelson, 1966, p. C8–C9); the lower Manicaboa intertongues with strata of the Río Orocovis Group (Berryhill, 1965, p. 46), whereas the Río Bauta Member rests on eroded Río Orocovis strata.

It seems that either the unconformity at the base of the Río Bauta Member has no counterpart in the Manicaboa Formation only 4 km to the north, or an equivalent unconformity is present in the middle or upper Manicaboa section but has been overlooked in the generally sparse and discontinuous exposures of the area (fig. 6, section *A–A″*).

BOTIJAS LIMESTONE MEMBER

The Botijas Limestone Member of the Coamo Formation was first described by Briggs and Gelabert (1962) in the Barranquitas quadrangle. As stated above, the assignment of strata in the northwestern Barranquitas quadrangle, including the Botijas Limestone Member, to the Coamo Formation has since been found erroneous; the Botijas Member is here reassigned to the Pozas Formation (fig. 5). Otherwise the description remains unchanged.

REVES MEMBER

This unit was first described by Briggs and Gelabert (1962) as the La Revés Member of the Coamo Formation; a printing error caused it to appear on the explanation of the geologic map as the El Revés Member. For simplicity the name of this member is here shortened to the Revés Member, and the unit is reassigned to the Pozas Formation (fig. 5), for reasons stated above. The description is otherwise unchanged.

AGE OF AND CORRELATIONS WITHIN THE POZAS FORMATION

The age of the Pozas Formation was defined broadly in the Ciales and Florida quadrangle reports. Chief evidence was from the Flor de Alba Limestone Lentil, which was cited as Late Cretaceous, Campanian and (or) Maestrichtian, in age (Nelson and Monroe, 1966, p. C12). In other studies of collections from the Flor de Alba Limestone Lentil, this age range has been determined to be late Campanian to early Maestrichtian (N. F. Sohl, written commun., 1965).

Extensive fossil collections have been made from the Río Bauta Member by Sohl. On the basis of preliminary studies, he has concluded that collections from the Río Bauta Member are Late Cretaceous, late Santonian through Campanian, in age. Further work suggests an assignment of early Campanian or perhaps latest Santonian age (N. F. Sohl, written commun., 1965).

The Botijas Limestone Member was assigned provisionally to the Upper Cretaceous Series, the Maestrichtian Stage, by Sohl (Briggs and Gelabert, 1962). More recent studies confirm this assignment (N. F. Sohl, written commun., 1965). The Revés Member of the Pozas Formation also is Late Cretaceous, Maestrichtian, in age (Briggs and Gelabert, 1962).

No other units within the Pozas Formation have yielded diagnostic fossil collections.

In summary, ages of fossil-bearing units in the Pozas Formation are as follows (from oldest to youngest): (1) Río Bauta Member, late Santonian to late Campanian, probably early Campanian, possibly latest Santonian, (2) Flor de Alba Limestone Lentil, late Campanian to early Maestrichtian, (3) Botijas Limestone Member, Maestrichtian, and (4) Revés Member, Maestrichtian. Therefore, the Pozas Formation is Late Cretaceous in age, ranging from late Santonian to Maestrichtian, more likely early Campanian to Maestrichtian.

The Río Bauta Member, 100 m thick, is the oldest unit in the Pozas Formation. It is correlated with the upper part of the Manicaboa Formation, and the Minguillo Lava and Blacho Tuff

Members in the Ciales quadrangle both rest on the Manicaboa Formation (Berryhill, 1965). The Minguillo Lava Member, 0 to 300 m thick, is overlain by the Blacho Tuff Member, which is 500 m thick in the type area. Berryhill does not state whether the Blacho Member is thicker or thinner where it rests on the Minguillo Member than it is to the south where it rests directly on the Manicaboa Formation, but a cross section seems to indicate a rather constant thickness for the Blacho Member in the Ciales quadrangle (Berryhill, 1965, pl. 3, section *A–A'*). However, recent work by the writer of this paper indicates that the Blacho Tuff Member is at least 700 m thick in the vicinity of the boundary between the Orocovis and Ciales quadrangles. An interpretation of the relations between these three members of the Pozas Formation and the Manicaboa Formation is shown in figure 6.

The Flor de Alba Limestone Lentil, 0 to 200 m thick, occurs within the upper breccia member of the Pozas in the Florida and Ciales quadrangles, about 600 m above the Blacho Tuff Member and about 800 m below the uppermost exposed Pozas strata (Nelson and Monroe, 1966).

The Botijas Limestone Member and the overlying Revés Member both occur in the upper part of the Pozas Formation. They crop out only in the Orocovis and Barranquitas quadrangles, where they generally range from 100 to 350 m in aggregate thickness. Faulting has made it impossible to measure the full stratigraphic interval between the Blacho Tuff Member and the Botijas Member, but at least 450 m of upper Pozas is exposed beneath the Botijas Member. About 500 m of Pozas is exposed above the Revés Member, but, as is the case in the Florida quadrangle to the west, the top of the Pozas is cut out by faulting (Briggs and Gelabert, 1962).

In the Florida, Ciales, and northwestern Orocovis quadrangles, nearly continuous exposures show that the Pozas Formation is 2,000 m or more thick and that the top of the formation is missing. About 1,200 m of this section (the Flor de Alba Lentil and subjacent rocks) is known to be older than the Botijas and Revés Members and superjacent rocks of the Pozas to the east, which may total more than 850 m in thickness.

Thus, if none of the Pozas strata exposed above the Flor de Alba Lentil in the Florida quadrangle are as young as the Botijas Limestone Member, the total thickness of the exposed Pozas strata is about 2,850 m. However, such a straight summation of thicknesses may be misleading owing to the well-known lenticularity of volcanic strata. An interpretation of relations in the upper Pozas is included in figure 6 (section *B–B'*).

THE TOYOSA MEMBER OF THE UPPER CRETACEOUS MARAVILLAS FORMATION

The Maravillas Formation was described by Mattson (1967, p. 16–18) in the Jayuya quadrangle as a moderately thick unit of feldspar-hornblende crystal tuff and thin-bedded calcareous tuffaceous sandstone that locally contains lenses of limestone.

In the Coamo quadrangle, Glover (1961) described a homogeneous unit of similar crystal tuff at the base of the Coamo Formation which he named the San Diego Lapilli Tuff Member. Overlying the San Diego Member, or separated from it by a few meters of tuffaceous sandstone, is the Santa Ana Limestone Member, a lenticular unit of gray finely crystalline limestone. Below the San Diego Lapilli Tuff Member is a discontinuous limestone unit, named the Sabana Hoyos Limestone Member of the Cariblanco Formation (Glover, 1961).

Recent mapping by the writer of this paper in the Orocovis quadrangle, between the Jayuya and Coamo quadrangles, has demonstrated that the San Diego Lapilli Tuff Member (now called San Diego Member, Glover, 1969) is traceable into and forms the bulk of the Maravillas Formation (fig. 7). Moreover, the Sabana Hoyos Member also has been traced across the Orocovis quadrangle into the Maravillas Formation, and strata considered by the writer to be generally equivalent to the Santa Ana Member are similarly traceable. Glover (1969) has accepted this correlation, has redefined the Coamo Formation to include only rocks overlying the Santa Ana Limestone Member, and has restricted the Cariblanco Formation to rocks beneath the Sabana Hoyos Limestone Member. In the Coamo area the Maravillas Formation, including the Sabana Hoyos, San Diego, and Santa Ana Members, now is recognized between the Cariblanco and Coamo Formations (fig. 2).

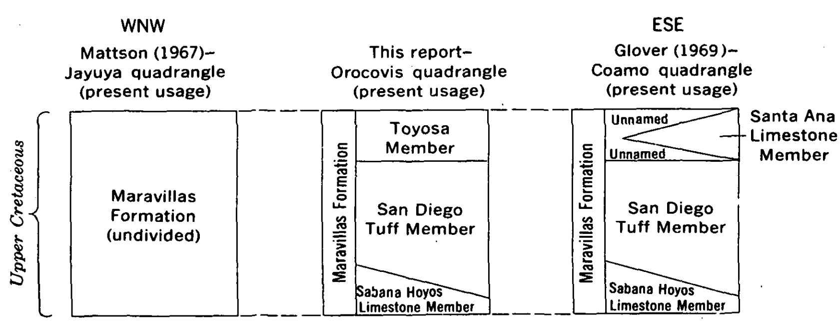

FIGURE 7.—Regional variations in the Maravillas Formation.

The Santa Ana Limestone Member as defined by Glover (1961) is composed chiefly of crystalline limestone; in the Coamo area the relatively minor occurrences of calcareous tuffaceous sandstone that are found beneath the Santa Ana Member or in positions stratigraphically equivalent to this member were not included in the Santa Ana Member by Glover (fig. 7). In the Orocovis quadrangle, however, the proportions of rock types in this stratigraphic interval are different; calcareous tuffaceous sandstone and tuffaceous calcarenite are found to form sections as much as 350 m thick, and the limestone lenses that typify the Santa Ana Limestone Member are absent in much of the area and are only a rather small part of the overall calcareous section where they do occur. The restrictive description of the Santa Ana Limestone Member does not allow extension of this stratigraphic name to the Orocovis quadrangle occurrences. Instead, a new name, the Toyosa Member, is here applied to these beds (fig. 7).

TOYOSA MEMBER

The Toyosa Member of the Maravillas Formation is here named for Montes la Toyosa, a hill slightly less than 700 m in elevation in the south-central part of the Orocovis quadrangle, centering about 6.8 km east-northeast of the town of Villalba (fig. 1). The Toyosa Member is exposed intermittently over the top and south flank of Montes la Toyosa and in the Río Toa Vaca along the southeastern and southern sides of the hill; however, the most accessible continuous exposures of the Toyosa Member are about 2.8 km west of Montes la Toyosa, along Highway 111 from about 34,460 m N., 149,370 m E. eastward to the junction of Highways 111 and 553, then southward along Highway 553 to 33,820 m N., 150,000 m E. This series of exposures is designated the type section.

In the type section, sharply defined thin to medium beds of calcareous tuffaceous sandstone and siltstone composed largely of feldspar grains in the lower part grade upward into medium and thick beds of similarly composed calcareous tuffaceous sandstone that have graded bedding and both sharp and gradational bedding contacts. Locally, fine calcareous breccia that contains fragments composed of finer tuff is interleaved with the sandstone. Some beds in the lower and middle parts of the section are more calcareous than others; these might well be described as tuffaceous calcarenite and, rarely, calcilutite. Where fresh, the rocks are medium gray to dark bluish gray, but strata in the upper part of the type section have been leached of most calcite, and beds commonly are grayish and yellowish brown.

Similar rocks form major parts of the Toyosa Member elsewhere; variants are the thin- to medium-bedded calcarenite that forms a slabby cover over part of the south slope of Montes la Toyosa and thick and very thick lenses of medium-gray, rather pure, finely crystalline limestone, such as that forming the walls of the Río Toa Vaca water gap southwest of Montes la Toyosa.

In the type section, the Toyosa Member of the Maravillas Formation is overlain conformably but rather sharply by commonly dark-red and dusky-red-purple very thick and thick volcanic strata of the Coamo Formation. The lower contact of the Toyosa Member is not well exposed in the type section. Although the underlying San Diego Member most commonly is noncalcareous, its upper part locally contains calcareous beds; the water-laid, but chiefly unreworked, crystal tuff of the San Diego Member appears to grade into the probably somewhat reworked tuffaceous sandstone of the Toyosa Member. In mapping, the contact commonly was drawn at the top of the highest bed that bears conspicuous quantities of the hornblende crystals which are characteristic of the San Diego Member.

Fragments in the Toyosa Member commonly are so fine that recognizable fossils have been recovered from only a few localities. In the type section, however, fossils indicate that the Toyosa Member is Late Cretaceous in age, probably Campanian and possibly ranging into the Maestrichtian (N. F. Sohl, written commun., 1965; Kauffman, 1964).

The lithologic changes, from strata typical of the Santa Ana Limestone Member in the Coamo area west-northwest to the Toyosa Member in the Orocovis quadrangle and the undivided Maravillas Formation in the Jayuya quadrangle (Mattson, 1968), are gradational, and placing the site of these changes is an arbitrary matter. The Toyosa Member of the Maravillas Formation therefore has been mapped only in the Orocovis quadrangle, where it is well exposed and well defined (fig. 7). In the Coamo area this part of the section has a different character, and in the Jayuya quadrangle limited exposures precluded mapping the Toyosa Member separately from the bulk of the Maravillas Formation.

Strata assigned to the Toyosa Member generally range from 40 to 350 m in thickness, and the thickest section is south of Montes la Toyosa. In the vicinity of the type section the Toyosa Member generally ranges from 80 to 150 m in thickness.

SUMMARY

Present changes in the stratigraphic nomenclature of east-central Puerto Rico may be summarized as follows:

1. The Lower Cretaceous Torrecilla Breccia is formally established, replacing the informally described formation D, fomation K, and pre-Robles rocks in the Cayey, Comerío, and Barranquitas quadrangles, respectively. The Torrecilla Breccia is carried west into the Orocovis quadrangle and correlated with the Jayuya Tuff in the Jayuya quadrangle. The Aguas Buenas Limestone Member is redescribed and assigned to the base of the Torrecilla Breccia, and the Barros Tuff Member is described as occurring locally within the top of the Torrecilla Breccia (fig. 4).
2. The Lower Cretaceous Barrancas Limestone Member of the Magueyes Formation, Río Orocovis Group, is described; thus a formal name is given to the "limestone unit" of formation L in the Barranquitas quadrangle. Strata formerly included in formation L and the Cariblanco Formation in the northern Barranquitas quadrangle are reassigned, chiefly to formations of the Río Orocovis Group; however, formation L strata underlying the Barrancas Limestone Member probably are stratigraphically equivalent to the Torrecilla Breccia (fig. 5).
3. The Río Bauta Member is described as the oldest unit of the Upper Cretaceous Pozas Formation. The Botijas Limestone Member and Revés Member, previously included within the Coamo Formation, are reassigned to the Pozas Formation (fig. 5).
4. The Toyosa Member is described as the topmost unit of the Upper Cretaceous Maravillas Formation (fig. 7) in the Orocovis quadrangle.

With these changes, the Upper Cretaceous strata of east-central Puerto Rico are wholly contained in a series of consistent formal sequences, facilitating future discussion. The Lower Cretaceous stratigraphic nomenclature is still incomplete because the rocks stratigraphically beneath the Torrecilla Breccia are not now sufficiently well known to permit more than tentative classification.

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